Aging yields a smaller number of fixations and a reduced gaze amplitude when driving in a simulator

M. Lavallière M. Tremblay V. Cantin
M. Simoneau N. Teasdale

Université Laval, Faculté de médecine, Division de kinésiologie. PEPS,
Québec, Québec, Canada G1K
email: Normand.Teasdale@kin.msp.ulaval.ca

Abstract

With the increasing number of elderly drivers, it is important to better understand if strategies for capturing visual information are affected by age and by the complexity of the driving contexts. Ten young (aged 21-31 years) and older (aged 65-75 years) active drivers drove through a continuous simulated scenario (STISIM, v2.0). The scenario included driving on open roads (less demanding), stopping at intersections and passing maneuvers (more demanding). Eye movements were recorded with an oculometer (ASL, model 510). Compared to younger drivers, older drivers showed a smaller horizontal amplitude between fixations and a smaller variance in the amplitude of the eye movements. They also showed a smaller number of fixations/sec for the more complex driving maneuvers that were analyzed (passing maneuvers). Overall, this may reveal a "tunnel effect" (or perceptual narrowing) phenomenon when the driving context increases in complexity.

Keywords - driving, simulator, gaze, aging

1. Introduction

Driving a car is a complex task requiring the driver to select and process visual information from various sources (for example, road signs and the behavior of other cars) before proper motor responses for controlling the vehicle are planned and executed. In everyday life, the pattern of eye-movements is thought to be a top-down mechanism [1, 4] characterized by specific learned pattern of fixations (for a recent review of this work, see [5]). For instance, in their landmark work, Mourant and Rockwell [6] reported that novice drivers concentrated their fixations in a smaller area (smaller range of horizontal scanning) and sampled their mirrors less frequently than experienced drivers. More recently, Crundal and Underwood [7] reported smaller horizontal variance for novice than experienced drivers. Interestingly, they also showed search strategies that differed as a function of the driving context; experienced drivers showed long fixations on the rural roads where there were few hazards and shorter fixations on the dual-carriageways where there were multiple hazards whereas novices tended to look longer on the dual-carriageways.

These differences were not simply the consequence of a greater mental workload associated with controlling the car for the novice drivers because similar observations were made when drivers were simply watching film clips recorded from the driver's perspective [8]. Underwood et al. [8] suggested that novice drivers have an incomplete mental model of the driving task, particularly in more complex driving contexts, which yielded to a reduced inspection of dynamics events on demanding roadways. Overall, the above work has been taken as strong support for the suggestion that, when driving, there are task-specific strategies serving to circumscribe the information available and to simplify the response selection process. Whether and how aging modifies the pattern of fixations is not well known, however. When static traffic scenes are presented without specific search instructions, Maltz et al. [9] reported longer search episodes for older than younger subjects.

The visual searches of older drivers were also characterized by more fixations and shorter saccades. With a search task requiring to identify particular traffic signs within a traffic scene, McPhee et al. [10] reported that older adults exhibited longer fixations when a simulated conversation was added. When cluttered scenes were presented, older adults were also less accurate to identify that a target sign was present and slower to decide that a target sign was not present. In a recent experiment, however, Underwood et al. [11] reported a lack of age difference in the scan pattern of older and younger drivers when watching film clips recorded from the driver's perspective. Their task, however, required drivers to identify hazardous contexts from film clips. These specific instructions could have triggered particular search strategies that, although they could be advantageous for driving, are not those normally adopted when driving. For older drivers, there are numerous databases showing that proportionally more accidents occur when the driving context increases in difficulty, for example at intersections [12, 15]. To explain these high rates of accidents, Hakamies-Blomqvist et al. [12] suggested that these difficult contexts could produce very high momentary mental workload; it is this mental workload that would yield driving errors. Using a divided-attention task, Hancock et al. [16] reported that turn sequences are more demanding than straight driving supporting the suggestion that more demanding traffic contexts may yield a cognitive overload.

These effects may be exacerbated for older drivers as several cognitive functions involved in driving decline with age (selected and divided attention, vigilance, etc.). Using a similar protocol to that of Hancock et al. [16] we showed that, when driving in a simulator, stopping at intersections needed more attentional demand than driving on straight roads (as indexed by longer RT), and passing maneuvers needed more attentional demands than stopping at intersections [17]. Older drivers also showed this effect but the more complex contexts exacerbated the cognitive demands [18].

In the present study, we built on this work and examined the scan patterns of younger and older drivers when driving in a simulator. The fixations were examined in three specific driving contexts (driving on open roads, stopping at intersections, and passing maneuvers) selected because they varied in complexity and in their cognitive demands. It was expected that, for the elderly drivers, driving through more complex contexts would yield fixations of longer durations with a reduced gaze amplitude and variance between successive fixations.

2. Methods

2.1. Subjects

Ten young subjects (20 to 31 years) and ten older drivers (65 to 75 years) participated (all males). All subjects were active licensed drivers (minimum of 3 years of driving experience for young drivers).

All participants reported having driven more than 5000 km in the preceding year. They were recruited through advertisements in local newspapers and aging coalitions. Upon their arrival in the laboratory, each participant was briefed on the requirements of the experiment and all read and signed an informed consent document. The experiment was reviewed and approved by the Université Laval Institutional Review Board. Then, subjects were given a general verbal questionnaire including items on driving (years of driving experience, frequency of driving and average km/week and year, presence of accident within the last years) and health in general (neurological and musculoskeletal problems, use of medication, drinking habits). Simple clinical tests (MMSE [19], Snellen visual acuity, Melbourne Edge test [20], ankle proprioception acuity, lower limb touch thresholds measured with a Semmes-Weinstein pressure aesthesiomether) were used to screen for impairments that might affect driving and cognition. All elderly scored 27 or higher on the MMSE and had normal or corrected to normal vision. Table 1 provides a summary of these results. Data for one older driver were not included in the eye movement analyses because of a ptosis problem (drooping eyelids).

2.2 Apparatus

Participants were tested in a fully interactive driving simulator. The simulator consists of an instrumented mid-sized sedan with automatic transmission (brake and accelerator pedals, steering and all manual controls) interfaced with programmable simulation software (STISIM v.2.0) [21]. The software allows to develop driving scenario and to record the driver's performance. Displacement of the accelerator and brake pedals and steering movements are recorded (Measurement Computing PCI-DAS08 12-bit A/D). The display system uses an Hitachi CP-X275 LCD projector to present the visual information on a flat wall (1.45 m high x 2.0 m wide) located 2.2 m from the steering. The center of the screen is located at eye level through the midline of the subject. The simulator offers a 40° horizontal by 30° vertical field-of-view. Blue curtains shield the peripheral information but that available on the front wall. Eye movements were monitored using an oculometer (Applied Science Laboratories, ASL, model 510, Cambridge, MA) at a sampling rate of 60 Hz. A head tracking device (Flock of birds) is included with the system to enhance the automatic tracking of the eye and to allow free head movements. A fixation was defined as three successive gaze positions (xy coordinates) staying within 1° of each other for a minimum duration of 100 ms.

2.3 Procedure

Subjects were made aware that simulators could make them feel uncomfortable. They were specifically instructed to inform the experimenter if this happened and were told the experiment would stop immediately without any prejudice for them. To reduce these sensations, the temperature within the room was maintained at about 17 C. The simulator is an open cab and ventilation is provided with a ceiling vent positioned just above the driver.

A 12-km practice scenario (with less graphical information than the experimental scenario) was also presented and served the purpose of familiarizing subjects with the simulator and the general feel of the pedals and steering. A 5-min rest between the practice and the experimental run was provided. With these measures, we have less than 5% of our subjects reporting sensations preventing them from pursuing the experiment. In the present experiment, all but 2 subjects reported being comfortable after the practice run. Data for these two subjects are not reported herein. The experimental run consisted of a continuous route of 26.4 km of urban and rural roads. The scenario included a normal driving environment (intersections with stop sign or crossing light, two-way and four-way roads, urban and rural areas) that did not require any emergency braking response unless a driving error was made. Subjects were asked to follow speed limits and to comply with local traffic laws throughout the course of the experiment. To comply with the 40 degree field of view of our simulator, there were no right- or left-turn maneuvers at intersections. Also, the smallest radius for the curves was 408 feet. This is sometimes considered a limitation of simulators as subjects do not go through maneuvers that are considered more complex (e.g. right-turn at an intersection).

As for on-the-road maneuvers [16], however, more complex maneuvers require greater cognitive demands and driving straights on open roads require less cognitive demands than stopping at intersections, while stopping at intersections require less cognitive demands than more complex passing maneuvers [17, 18]. We built on this work and recorded eye movements for 26 segments of 100 m within the overall scenario (open road sections, n=6; intersections where the driver needed to stop, n=15; passing maneuvers, n=5). The number of segments is not counterbalanced for each different type of driving context. We feel this is a necessary compromise to attain some ecological validity. For the passing maneuvers, a recorded message indicated in advance to the driver that he would encounter a slower vehicle and that he should safely pass this car. For instance, for one of the passing maneuvers, the verbal message was presented when driving on an initial one-way route segment through an urban landscape. This roadway opened onto a long two-lane straight section with slow trucks ahead of the driver. Recording of eye movements always started before the actual passing maneuver.

2.4 Data analyses

Gaze amplitude (along the horizontal axis) and mean number and duration of fixations were analyzed for each segment. All variables were submitted to 2 x 3 (Groups x Driving contexts) ANOVAs with repeated measures on the last factor. When needed, means were compared with the Tukey post-hoc test ($p<0.05$).

Tab. 1 - Summary of results for the general health evaluation and driving experience.
Mean (Standard deviation)

	Young drivers	*Elderly drivers*	*P values*
Age	24 (3.53)	69.4 (2.95)	< 0.001
Years of experience	7 (2.4)	47.5 (5.33)	< 0.001
Accident within the last years	0.6 (0.8)	0.7 (0.7)	> 0.05
Alcohol beverages per week	3.4 (3.9)	3.1 (3.8)	> 0.05
MMSE	28 (1.15)	27.2 (0.42)	> 0.05
Snellen visual acuity High contrast	0.88 (0.25)	1.02 (0.17)	> 0.05
Snellen visual acuity Low contrast	1.21 (0.36)	1.61 (0.63)	> 0.05
Melbourne edge test	21.7 (1.5)	19.3 (1.3)	< 0.01
Ankle proprioception acuity (mean for 5 trials)	1.55 (0.57)	2.4 (0.75)	< 0.05
Lower limb touch thresholds	4.2 (0.3)	4.3 (0.3)	> 0.05

3. Results

3.1 Driving performance

Overall, the time required to complete the experimental scenario was longer for older than for young driver (on average, 30.7 min vs. 25.6 min.; $p<0.01$). We observed only 1 accident. This accident was for one elderly driver and a review of the accident showed that this driver never looked at the crossing light in the 100 m preceding the intersection. The driver went through the red light and this yielded a side crash.

3.2 Number of fixations and duration of the fixations

Older drivers showed a greater number of fixations than younger drivers and this was observed for all three driving contexts (on average, 23.4 vs 18.1 fixations;$P<0.05$ for the main effect of Group and $P>0.05$ for the interaction of Group x Driving context). The main effect of Driving context was statistically significant ($p<0.05$); both groups showed more fixations when stopping at intersections than during passing maneuvers and both contexts yielded more fixations than driving on open roads (14.2, 26.8, and 21.2 fixations for open roads, stopping at intersections and passing maneuvers, respectively; $p<0.05$).

Some of these differences could result from the slower driving of the older drivers. For this reason, we also computed the number of fixations/sec.

Fig.1 shows the normalized number of fixations for all driving contexts. The ANOVA yielded a significant main effect of Driving context and a significant interaction of Group by Driving context ($p<0.01$). The main effect of Group was not statistically significant ($p>0.05$). More fixations per sec were observed when driving on open roads and during passing maneuvers than when stopping at intersections ($p<0.01$).

A decomposition of the interaction into its simple main effects showed that a significant Group difference was observed only for the passing maneuvers where the older drivers showed less fixations per sec than younger drivers ($p<0.01$).

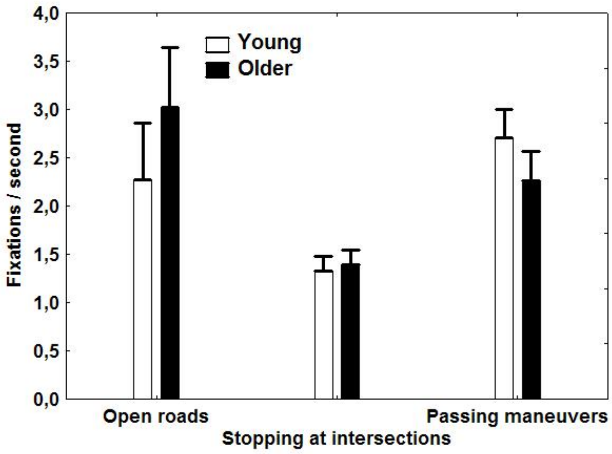

Fig. 1 - Mean normalized number of fixations (per second).
Confidence intervals (95% of the data distribution) are also presented

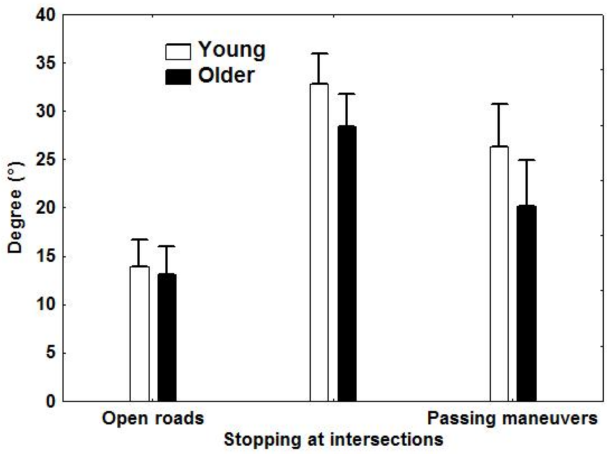

Fig. 2 - Mean horizontal amplitude of fixations(deg).
Confidence intervals (95% of thedata distrbution) are also presented

For the duration of the fixations, older drivers showed longer fixations than younger drivers (on average, 375 ms vs 340 ms for the older and younger drivers, respectively) but this effect did not reach the significance level (p>0.05). The ANOVA showed a main effect of Driving context only (p<0.05; p>0.05 for the interaction of Group x Driving context).

A comparison of means showed that, on average, the duration of the fixations was longer when driving on open roads than when stopping at intersections (377 ms vs 338 ms; p<0.05). All other comparisons were not significant (p>0.05; 353 ms for the mean duration of the fixations for the passing maneuvers).

3.3 Horizontal gaze amplitude

For each subject, we computed the horizontal amplitude of the gaze. Figure 2 presents the amplitudes for each driving contexts. The ANOVA yielded main effects of Group (p<0.05) and Driving contexts (p<0.05). The interaction of Group by Driving context was not significant (p>0.05). Older drivers showed a reduced gaze amplitude in comparison with younger drivers (on average, 20.6 vs 24.3 deg). For both groups, the horizontal amplitude was smaller when driving on open roads than for the other two contexts (p<0.05). It was also greater when stopping at intersections than for passing maneuvers (p<0.05). We also looked at the variance of the eye movements (that is, the standard deviation of the gaze amplitude within a segment).

The results mimicked those observed for the gaze amplitude. Older drivers showed less variance than younger drivers (on average, 2.2 deg vs 2.9 deg; p<0.05). The Group by Driving context was not statistically significant (p>0.05). The main effect of Driving context, however, was significant (p<0.001) and the variance was smaller when driving on open roads than for the two other driving contexts (on average, 1.7 deg vs 2.9 deg and 2.9 deg for the open roads, stopping at intersections and passing maneuvers, respectively).

Figure 3 illustrates dispersion of fixations for both groups. For each driving context, one can appreciate the more dispersed fixations for the younger than for the older drivers. Also, for the older drivers, there is a greater density of fixations around the center of the screen.

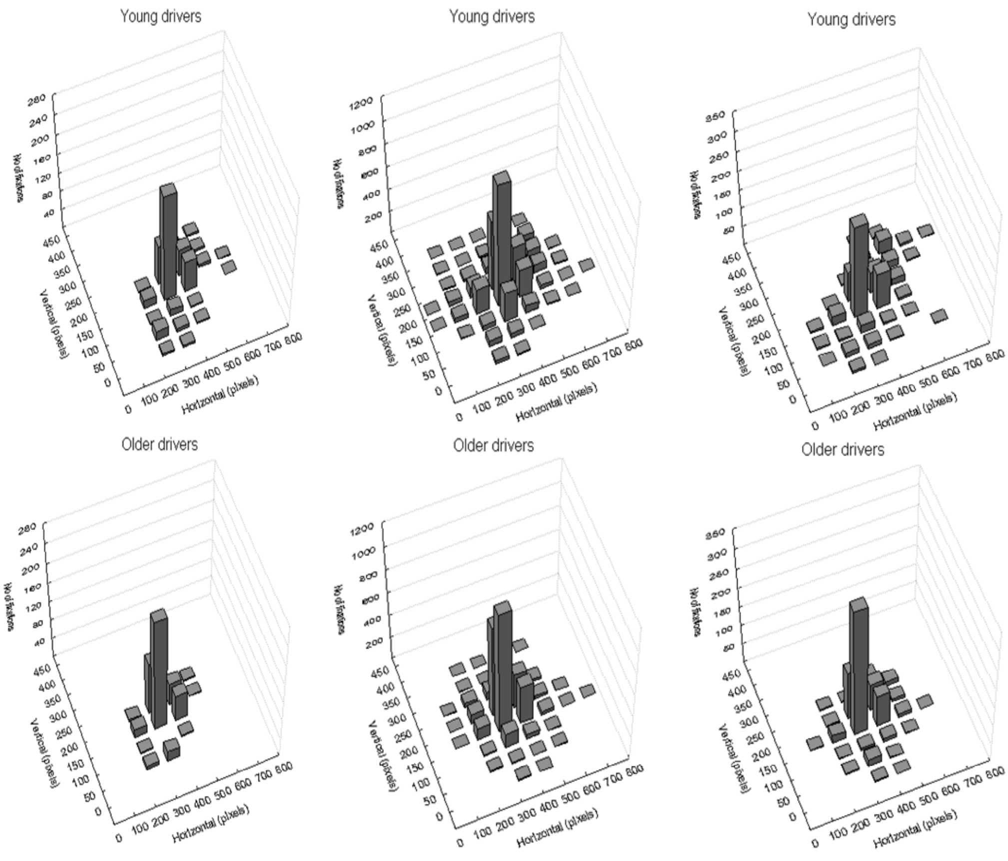

Fig. 3 - Density histograms of the fixations for open roads (left), stopping at intersections (middle) and passing maneuvers segments (right). Each column represents an area of 100 pixels (horizontal) by 50 pixels (vertical) or 5.5 deg by 3.1 deg. Data presented are for all subjects in each group

4. Discussion

The elderly tested in the present experiment were healthy and active drivers. Also, the driving conditions were as normal as possible and we did not present any contexts requiring emergency braking responses. Nevertheless, we were able to document subtle age-related differences in the gaze behavior of the participants. Compared to younger drivers, older drivers showed a reduced gaze amplitude and a reduced variance for the three driving contexts examined. Also, when the driving context was more complex (passing maneuvers), older drivers showed a smaller number of fixations/sec than younger drivers suggesting that older drivers did not sample the environment in the same manner as their younger counterpart.

These observations are important as the scenarios presented were not highly demanding driving contexts.

Despite this fact, the differences suggest an age-related perceptual narrowing (or tunnel effect) that could be exacerbated when facing more complex driving maneuvers. The smaller gaze amplitude and variance have sometimes been taken as illustrations of this phenomenon (perceptual narrowing).

For instance, Rogé et al [22] reported that older drivers had a reduced ability to detect a stimulus presented in peripheral vision during a monotonous driving task consisting of following a vehicle in road traffic for a two-hour period. Several comparisons between novice and more experimented drivers also suggest the possibility of a perceptual narrowing phenomenon. For instance, Mourant and Rockwell [6] reported that novice drivers concentrated their fixations in a smaller area (smaller range of horizontal scanning) and sampled their mirrors less frequently than experienced drivers.

More recently, Pollatsek et al [23] reported that novice drivers fixated risky features of simulated scenarios less often than young and older drivers. In one experiment, the ability to detect peripheral stimuli interacted with the complexity of contexts with novice drivers showing a reduced detection when potentially hazardous situations became visible in a video clip [Crundall 2005, reported in 5].

There are very few studies showing this effect with elderly drivers, however. When static traffic scenes are presented without specific search instructions, there are reports of age-related deficits [9, 10] with the elderly generally showing less accurate fixations taking more time to identify the presence of specific targets (traffic signs) in a scene. When video clips recorded from the drivers' perspective were presented, Underwood et al. [11] reported a lack of age difference in the scan pattern of older and younger drivers. Pollatsek et al [23] also reported that older and younger drivers fixated as often to risky features of simulated scenarios. This was not the case for novice drivers which showed a smaller percentage of trials for which they fixated risky features. Underwood et al [8] suggested that novice drivers have an incomplete mental model of the driving task, particularly in more complex driving contexts, which yields to a reduced inspection of dynamics events on demanding roadways. It is difficult to reconcile completely our observations of a smaller gaze amplitude (and reduced variance) for the elderly with those of Underwood et al. [11] and Pollatsek et al. [23].

There is a possibility that the presentation of specific hazardous events could have triggered particular search strategies that, although they could be advantageous for driving, are not those normally adopted when driving. For instance, our level of alertness is always awakened after a hazardous event but this state of alertness is not always as high. By presenting several such situations in a limited time, one could artificially raise the level of alertness. This is reminiscent to what Poulton referred as a bias in quantifying judgments [24, 26]. This is a possibility that should not be discarded too rapidly.

A limitation of our study is that we have not yet determined the specific patterns of fixations. Hence, it is not possible to determine what information was missed by older drivers by reducing their gaze amplitude and variance. We have analyzed the scan patterns for a few segments. For instance, the only accident observed occurred after an elderly driver omitted to glance at the red light.

This, obviously, is anecdotal and a more detailed and rigorous analyses of the scan patterns could unravel age-related differences. The recent work of Pollatsek et al. [23] and Underwood et al. [8] suggests that identifying more precisely the gradual changes in the scan pattern, whether it is when learning to drive or through the normal aging process, could provide important insights for determining skilled from unskilled drivers.

References

1. Hayhoe, M., Ballard, D. (2005). Eye movements in natural behavior. *Trends in Cognitive Sciences,* 9, 188-94
2. Yarbus, A.L. (1967). Eye movements during perception of complex objects. IN: Riggs, L. A. (Ed.) Eye movements and vision. New York, Plenum Press.
3. Shinoda, H., Hayhoe, M.M., Shrivastava, A. (2001). What controls attention in natural environments? *Vision Research,* 41, 3535-45
4. Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin,* 124, 372-422
5. Land, M.F. (2006). Eye movements and the control of actions in everyday life. *Progress in Retinal and Eye Research,* 25, 296-324
6. Mourant, R.R., Rockwell, T.H. (1972). Strategies of visual search by novice and experienced drivers. *Human Factors,* 14, 325-335
7. Crundall, D., Underwood, G. (1998). The effects of experience and processing demands on visual information acquisition in drivers. *Ergonomics,* 41, 448-458
8. Underwood, G., Chapman, P., Brocklehurst, N., Underwood, J., Crundall, D. (2003). Visual attention while driving: sequences of eye fixations made by experienced and novice drivers. *Ergonomics,* 46, 629-46
9. Maltz, M., Shinar, B. (1999). Eye movements of younger and older drivers. *Human Factors,* 41, 15-25
10. McPhee, L.C., Scialfa, C.T., Dennis, W.M., Ho, G., Caird, J.K. (2004). Age differences in visual search for traffic signs during a simulated conversation. *Human Factors,* 46, 674-85
11. Underwood, G., Phelps, N., Wright, C., van Loon, E., Galpin, A. (2005). Eye fixation scanpaths of younger and older drivers in a hazard perception task. *Ophthalmic and Physiological Optics,* 25, 346-56
12. Hakamies-Blomqvist, L., Mynttinen, S., Backman, M., Mikkonen, V. (1999). Age-related differences in driving: Are older drivers more serial? *International Journal of Behavioral Development,* 23, 575-589
13. Cooper, P.J. (1990). Differences in accident characteristics among elderly drivers and between elderly and middle-aged drivers. *Accident Analysis and Prevention,* 22, 499-508
14. Hauer, E. (1988) The safety of older persons at intersections. Transportation in an aging society. Washington, DC, Transportation Research Board.
15. Owsley, C., Ball, K., McGwin, G., Jr., Sloane, M.E., Roenker, D.L., White, M.F., Overley, E.T. (1998). Visual processing impairment and risk of motor vehicle crash among older adults. *Journal of the American Medical Association,* 279, 1083-8
16. Hancock, P.A., Wulf, G., Thom, D., Fassnacht, P. (1990). Driver workload during differing driving maneuvers. *Accident Analysis and Prevention,* 22, 281-90
17. Teasdale, N., Cantin, V., Blouin, J., Simoneau, M., Desroches, G. (2004). Attentional demands while driving in a simulator: Effects of driving straights on open roads and when approaching an intersection. *Advances in Transportation Studies: An International Journal,* Special issue, 29-38
18. Teasdale, N., Cantin, V., Lavallière, M., Tremblay, M., Simoneau, M. (2006). Age-related attentional demands while driving in a simulator. *4th Annual STISIM Drive User Group Meeting, New Approaches to Simulation and the Older Operator.* MIT (Massachusetts).
19. Folstein, M.F., Folstein, S.E., McHugh, P.R. (1975). Mini-mental state. A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research,* 12, 189-198
20. Verbaken, J.H. (1989). Contrast sensitivity testing with low contrast acuity charts: manufacturer's guide. Melbourne, Australia, Australian Vision Charts.
21. Allen, R.W., Rosenthal, T.J., Aponso, B.L., Klyde, D.H., Anderson, F.G., Hogue, J.R., Chrstos, J.P. (1997). A Low Cost PC Based Driving Simulator for Prototyping and Hardware-In-The-Loop Applications. *SAE International Congress & Exposition,*
22. Roge, J., Pebayle, T., Lambilliotte, E., Spitzenstetter, F., Giselbrecht, D., Muzet, A. (2004). Influence of age, speed and duration of monotonous driving task in traffic on the driver's useful visual field. *Vision Research,* 44, 2737-44

23. Pollatsek, A., Narayanaan, V., Pradhan, A., Fisher, D. (2005). Using eye movements to evaluate a PC-based risk awareness and perception effects of driver age on risk perception in a driving simulator. *Human Factors,* 47, 840-52
24. Poulton, E. (1989). Bias in quantifying judgments. London, Laurence Erlbaum Associates.
25. Poulton, E.C. (1969). Bias in experimental comparisons between equipments due to the order of testing. *Ergonomics,* 12, 675-87
26. Poulton, E.C., Freeman, P.R. (1966). Unwanted asymmetrical transfer effects with balanced experimental designs. *Psychological Bulletin,* 66, 1-8